CHAPTER

3

Economic Growth

In this chapter we assemble a model of **long-run economic growth.** The long-run economic growth model is designed to explain the general upward path of output over time.

By describing the upward trend in the economy, the long-run growth model enables us to address many crucial economic policy issues. Most importantly, it can help to explain why the trend in economic growth has declined in the United States in the past two decades and why economic growth differs greatly in different regions and countries of the world. Small differences in the economic growth rate make enormous differences in economic well-being. A growth rate difference of just 6 percent per year enabled income per capita in the U.S. South to rise from only 40 percent of the North's after the Civil War to almost the same as the North's today. If the growth rate in the United States had been the same since the 1970s as it was in the 1950s and 1960s, then production in the United States would have been about 1.7 trillion dollars more in 1995. That would be $6,600 per year for every man, woman, and child in the United States, or about six times the national defense budget. That "lost" production could have been put to use in many ways: a higher standard of living for Americans, including the poor; more investment in plant, equipment, and infrastructure; less dependence on foreign resources. But because the growth rate slowed down, those resources have not been available.

The long-run growth model does not try to explain the departures of the economy from its growth trend. Hence, it does not explain important events like the 1990–91 recession or the increase in unemployment that occurred at that time. Unlike the complete model, which is examined starting in Chapter 6, the long-run growth model abstracts from these short-run fluctuations. We use it to project economic conditions in the more distant future and to understand variations in growth rates.

The long-run growth model describes the economy in a state where supply and demand for both goods and workers are in balance. Wages and prices have moved as needed to equate supply and demand. Incentives are having their full effect in inducing an efficient level of production.

3.1 THE DETERMINANTS OF ECONOMIC GROWTH

There are three important determinants of the long-run growth path of output:

1. *Labor*—the people available for work
2. *Capital*—equipment, structures, and other productive facilities
3. *Technology*—the knowledge about how to use labor and capital to produce goods and services

Labor

Growth in the number of people available for work is an important source of the growth of GDP. Since the 1970s growth in the number of workers has been strong as the post–World War II baby boom generation came of working age and women entered the labor market in large numbers. Growth in the future is expected to be weaker.

Not everybody in the population is in the labor force. It is against the law for children to work; many adults are in school, working at home, or in retirement, and quite a few others are unable to work because they are disabled or sick. Some people are committed to working full-time no matter what the incentives; others will choose the level of their work effort depending on the incentives provided by the labor market. About 7 percent of the working-age population was in the labor force in 1996. This percentage—the **labor force participation rate**—has been steadily increasing during the last 20 years, primarily because of increasing participation rates for women.

Another important fact about the labor market is that at any given time not everybody who is in the labor force and available for work is actually employed. Unemployment is a feature of the economy even when supply and demand appear to be in balance. In February 1996, a good period for the economy, 5.5 percent of the labor force was unemployed during the typical week. Unemployment rises in recessions and falls in booms, but there is a certain level of unemployment called the **natural rate of unemployment.** The natural rate is the amount of unemployment when the labor market is in equilibrium. One simple measure of the natural rate is the average rate of unemployment over several decades. The natural rate appears to lie between 5 and 6 percent in the United States.

If we subtract the number of unemployed workers from the number of workers in the labor force, we get the number of workers employed. Production depends not only on the number of workers employed but also on the amount of hours they work each year. Hence, when looking at the effects of employment on production and growth, we count only the hours that workers actually work. The total number of hours worked in the economy in a given year is what we mean by *labor input.* We frequently refer to labor input simply as employment and label it N.

Capital

In any given year, the volume of physical capital—aircraft factories, computers, trucks, tractors, barns, clothing stores, etc.—is determined by investment in previous years. An increase in the amount of capital in the economy will enable the economy to produce more output. For example, a farmer with a tractor can produce tons more wheat than a farmer without a tractor. Boeing couldn't produce any 747s without manufacturing plants. The capital stock increases from one year to the next as long as gross investment is greater than the depreciation of the capital stock. As long as net investment is positive, the capital stock is growing. However, any investment project undertaken this year to increase the capital stock will not add to the stock until the project is complete, a process that takes time. We use the symbol K for the existing capital stock.

Technology

The third determinant of production—technology—tells us how much output can be produced from the amount of labor and capital used in production. Technology includes anything that influences the productivity of workers or capital. It includes technology in the usual sense of the word, such as a communications technology that enables a firm to fax a supplier an order form rather than send it by regular mail. It also includes how efficiently businesses are organized and managed.

We use the symbol A to represent technology. Technology is perhaps the most abstract of the three determinants of growth, and it is more difficult to measure than labor and capital. Fortunately, there are many vivid examples that can reduce the level of abstraction, such as the following automobile example.

HENRY FORD'S ASSEMBLY LINE. One of the great—and most visible—technological advances of the 20th century was Henry Ford's idea of mass production through the assembly line. Mass production greatly increased the productivity of workers and capital employed in the automobile industry, and eventually other industries as well. It represents an example of an increase in technology—an increase in A.

Ford's innovation occurred in 1913 at his Highland Park factory in Detroit, where he arranged an assembly line in which cars moved past workers who remained in place, rather than having the workers move around the factory. Observers at the time calculated that this one technological advance reduced the time it took a group of workers to assemble the major components into a complete car from 12½ to 1½ hours! With this increase in productivity it is not surprising that Ford could double wages to $5 a day and still cut prices.

Technological change increases the productivity of both labor and capital. Labor and capital are factors of production. Technological change may increase the productivity of both factors in a neutral way such that their marginal productivities increase in the same proportion. It is then useful to define technological change as something that increases *total factor productivity.*

The Production Function

A simple way to represent how the three determinants of production combine to produce output is through the **production function,** which shows how much output can be produced from given amounts of labor, capital, and technology. The production function can be represented using symbols as follows:

$$Y = F(N, K, A). \quad \text{The Production Function} \qquad (3.1)$$

This is simply shorthand notation for saying that output Y depends on employment N, capital K, and technology A. (Reading out loud we say "Y is a function F of N, K, and A.") The notation F followed by variables listed in parentheses means a general function of those variables. With such a notation we are not specific about what the function actually looks like, whether it is linear or the square root of N or whatever.

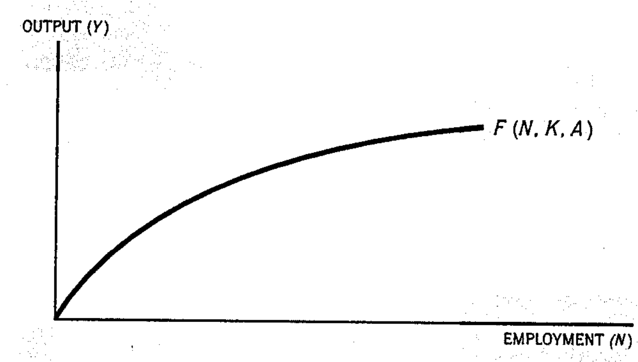


FIGURE 3.1 The Production Function in Terms of Labor Input

With a given capital stock and technology, the volume of output Y produced from various levels of employment N shows the diminishing marginal product of labor.

The production function relates output to employment, capital, and technology, whatever their levels. It tells us how much real GDP would be produced, for example, if there were a very severe depression and only half the normal number of people were at work.

Figure 3.1 shows how production depends on labor for a given capital stock and a given level of technology. The production function curves toward the horizontal axis. The **marginal product of labor** is the additional output that is produced by one additional unit of work. The marginal product of labor is the slope of the production function in Figure 3.1. Note how the production function gets less steep as more labor is employed. This means that the marginal product of labor declines as the amount of employment increases.

3.2 FULL EMPLOYMENT AND POTENTIAL GDP

The growth model assumes that the economy is at full employment, with the quantity of labor demanded equal to the quantity of labor supplied. We define potential GDP as the amount of production that occurs when labor is fully employed. In order to determine potential GDP, therefore, we must calculate the level of N corresponding to full employment. For now, we

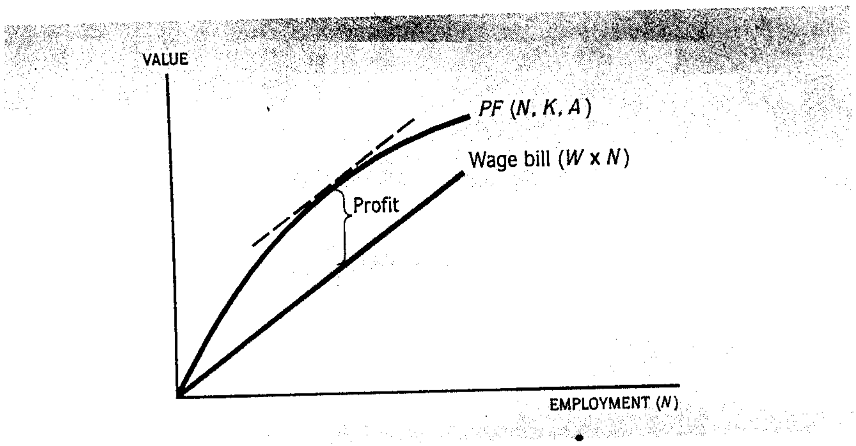


FIGURE 3.2 Profit Maximization

Profit is the difference between the value of output, P times $F(N, K, A)$, and the wage bill, W times N. It reaches a maximum when the slope of P times $F(N, K, A)$ equals the slope of W times N; that is, the value of the marginal product of labor equals the wage.

consider the level of technology A and the level of capital K as given. To find N, we consider the demand for, and supply of, labor.

The Demand for Labor

A first principle of microeconomics is that a profit-maximizing firm in a competitive market will choose the level of employment where *the marginal product of labor equals the real wage*. The **real wage** is the dollar wage W divided by the price level P, that is, W/P. If firms had employment below this level, the marginal product of labor would exceed the real wage and an opportunity for improved profit would exist. A firm could hire a worker for the wage W, produce more output in the amount given by the marginal product of labor, sell that output at price P, and make a profit on the deal. Firms will pursue this opportunity for profit until their additional hiring pushes the marginal product of labor down to the real wage. The point of maximum profit is shown in Figure 3.2.

The demand function for labor is a negative function of the real wage because the marginal product of labor declines with increased labor input, as shown in Figure 3.3.

The Supply of Labor

The supply of labor is determined by the decisions of individual workers

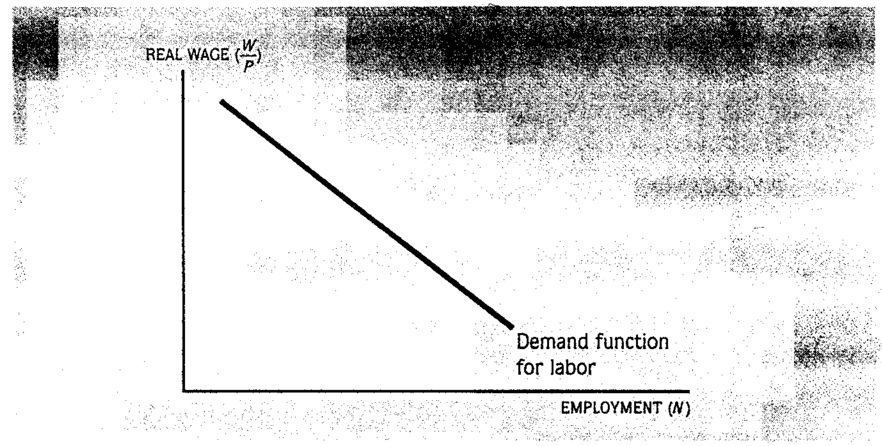


FIGURE 3.3 The Demand Function for Labor

The demand function for labor is a downward-sloping relation between the real wage, W/P, and the level of employment, N. For each real wage, it gives the level of employment that firms will choose by equating the marginal product of labor to the real wage.

the incentive to work. At higher real wages, those already at work will want to work more. In addition, a higher real wage may draw people into the workforce who would not work at all with a lower real wage. A higher real wage has an incentive effect toward more work. For most people, however, wages are the dominant source of income. When wages rise permanently, they are better off. People who are better off choose to spend more time at home and away from the job. On this account, permanently higher real wages bring lower labor supply. Microeconomic theory labels these two contrasting influences the substitution effect and the income effect.

SUBSTITUTION EFFECT. As something becomes more expensive, people substitute away from it. In the case of labor supply, as time at home becomes more expensive (as its opportunity cost, the real wage, rises), people substitute away from time at home and toward time in the labor market. To put it another way, the real wage provides an incentive for work, and people substitute toward work when the real wage rises.

INCOME EFFECT. As income rises, people tend to consume more of most things. In this case, they consume more of their own time at home and offer less of their time in the labor market. Permanently higher real wages make people better off, and they work less on that account

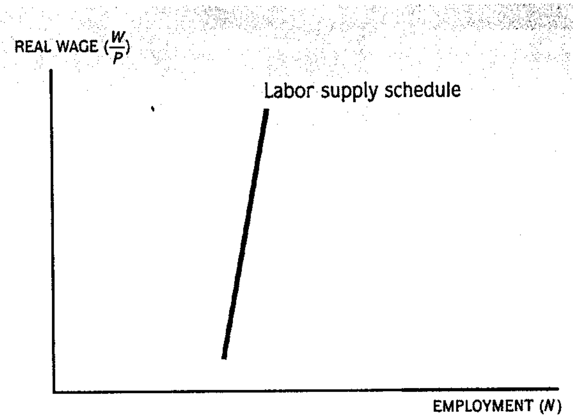


FIGURE 3.4 Long-Run Labor Supply Schedule

The labor supply schedule gives the amount of labor offered in the labor market for various levels of the real wage. When real wages rise permanently, the incentive to work is greater, but people have more income, and this tends to offset the incentive. The evidence suggests that the long-run labor supply schedule is almost vertical.

The long-run labor supply schedule, illustrated in Figure 3.4, shows the net effect of these two offsetting influences. Research by a number of economists has agreed rather closely that the net effect of the two influences of real wage on labor supply is roughly zero.[1] However, it is important to keep in mind that the agreement is that the *net effect* is approximately zero, not that each of its components is zero. The substitution effect, prompting people to work more when the real wage rises, has been shown to be strong in some studies. In these studies the income effect happens to be equally strong in the opposite direction.

Full Employment

Another principle of microeconomics is that employment will be at the intersection of the labor supply and labor demand schedules. The equilibrium is shown in Figure 3.5. On the vertical axis is the real wage, which is the ratio W/P of the dollar wage to the price level. In equilibrium at the real wage W/P, the quantity of labor N chosen by firms equals the quantity supplied by the public. In Figure 3.5, the labor market is in a standard microeconomic

[1]The most recent econometric studies have used experimental data or panel data of the type we describe in Chapter 10 in our analysis of consumption. A useful survey of available results is found in John Pencavel, "Labor Supply of Men: A Survey," in Orley Ashenfelter, ed., *Handbook*

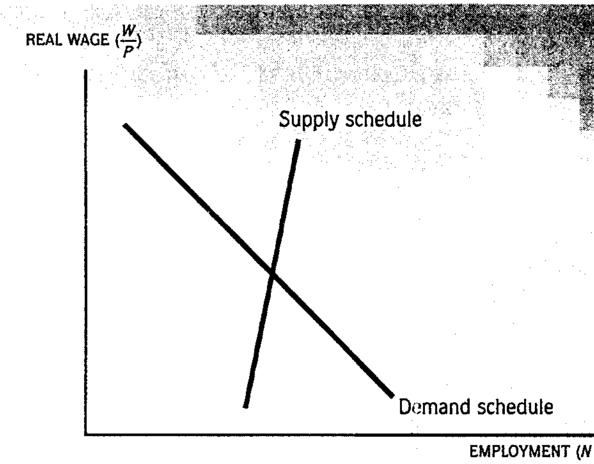


FIGURE 3.5 Labor Market Equilibrium

In the model with perfectly flexible wages and prices, the real wage is determined by the intersection of the supply and demand curves for labor.

equilibrium. Every worker is able to find a job. If the real wage were too high to provide jobs for everyone interested, the real wage would fall. The fall would stimulate labor demand by firms and discourage work effort by workers. The real wage would fall immediately to the point where the supply and demand curves intersect and everybody had work.

We define **full employment,** N^*, as the volume of employment at the intersection of supply and demand in Figure 3.5. It is the total amount of work that would be done if each worker could find a job after a brief search and earn as much as similar workers are already earning. Notice that full employment is not the absolute maximum amount of work that the population is capable of doing. It is the amount people want to work given the real wage that employers are willing to pay. If productivity rises, so that the labor demand schedule shifts upward, the equilibrium level of employment rises. Moreover, as the population grows, the labor supply schedule will shift to the right and equilibrium employment will rise.

Potential GDP

Potential GDP, denoted by Y^*, is the amount of output produced when the labor market is at full employment:

The level of output, Y^*, is the amount of output that would be produced if everybody who wanted to work could find a job. For this reason, Y^* is also frequently called the **full-employment level of output.** Recall that in Figures 1.1 and 1.2 we compared actual GDP with estimates of potential GDP. We found that potential GDP grows steadily, whereas actual GDP fluctuates around a growth trend.

POTENTIAL GDP AND THE LABOR MARKET

1. Potential GDP is the level of real GDP when labor is fully employed. Prices and wages have moved so that markets are in balance.
2. The determinants of potential GDP are the labor force and its willingness to work as expressed by the labor supply schedule, the capital stock, and the technology of the economy.
3. In the labor market, the real wage adjusts as needed to keep the market in balance. Full employment is the common value of labor supply and labor demand after the real wage has made the two equal.
4. When the labor market is in balance, there is still some unemployment. The natural rate of unemployment is between 5 and 6 percent in the United States.

3 THE SOLOW GROWTH MODEL

Having defined the production function in the previous two sections, we are now prepared to explore the behavior of the economy as it steadily grows through time. In particular, we want to look at the relationship between labor growth, capital growth, and technological growth and to examine whether the growth process has any inherent tendencies to slow down. We focus on a particular real-world example: the growth path of the United States economy from now into the first part of the twenty-first century.

The growth of the labor force is predicted by the Bureau of Labor Statistics to average around 1 percent per year from now through the year 2010. The forecast is very reliable, because the people who will be in the labor force—which is limited to those who are 16 years of age and over—during this time have already been born. Projecting the labor force much beyond 2010 is more difficult because it requires forecasting future birthrates.

Now consider the growth of the capital stock over the same future period. Capital growth will depend on how much investment there is each year, which in turn depends on how much Americans save and how much foreigners invest in the United States. Forecasting future saving and foreign investment is much more difficult than forecasting the growth of the labor force. Saving will depend not only on what private individuals do, but also on whether the federal government succeeds in reducing the budget deficit. Instead of trying to forecast future capital growth, we consider the implications of a future in which the growth rate of capital exactly equals the growth rate of labor, so that the amount of capital available for each worker neither rises nor falls. Such a steady growth path—called a **balanced growth path** because the growth rates of capital and labor are balanced—would be a useful baseline from which to make judgments about how alternative economic policies would affect the future. But first we need to check whether the economy tends to follow a balanced growth path.

Robert Solow of M.I.T., who won the Nobel Prize in 1987, wrote a paper in 1956 on balanced growth paths such as the one hypothesized.[2] In fact, the long-run growth model was introduced for the first time in that paper. Solow's model is sometimes called the *neoclassical growth model* because it built on the classical models used by economists before Keynes. The Solow analysis makes extensive use of the production function, the identities we discussed in Chapter 2, and a simple assumption about saving.

Saving and Balanced Growth

In the simplest version of Solow's neoclassical growth model, the economy is closed (so domestic saving equals investment) and there is no technological change (the term A is constant over time). Both assumptions can be modified, but they make it easier to see what is going on. Later in this chapter we will allow A to increase over time and even be determined endogenously within the growth model. Labor force growth is assumed to be at a constant rate, n. Each year the labor force increases by n times N, the level at the start of the year. Currently, growth of the labor force in the United States is about 1 percent per year, so $n = .01$.

We saw in Chapter 2 that the change in the capital stock equals net investment. If capital is to grow at the rate n, then each year capital must rise by the amount nK. In order to stay on a growth path where the capital stock grows at rate n, net investment must be nK each year. We can think of nK as *balanced growth* investment. For example, if the capital stock is \$10 trillion and n is 1 percent, then net investment must equal \$100 billion (.01 times \$10,000 billion) if the capital stock is to grow at the same 1 percent

[2] R. M. Solow, "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, Vol. 70 (February 1956), pp. 65–94.

rate as labor. To summarize, we have derived the first key condition for balanced growth:

$$\text{Net investment} = nK. \tag{3.3}$$

The second major element of Solow's analysis deals with saving. Saving depends on (1) the fraction of national income that is saved and (2) the level of national income. Let s be the fraction of income that is saved; s is called the *saving rate.* Saving in the economy is equal to s times income. We know from Chapter 2 that income equals output, Y. Hence,

$$\text{Saving} = sY. \tag{3.4}$$

For example, if income Y is \$5 trillion and the saving rate is .02, then saving would be \$100 billion. Since saving equals net investment, we see that sY equals the *actual* amount of net investment in the economy.

A subsidiary assumption of Solow's growth analysis is that the production function has *constant returns to scale.* Under constant returns and with unchanging technology, if there are equal proportional changes in labor and capital, output changes by the same proportion. Recall that the production function is

$$Y = F(K,N,A). \tag{3.5}$$

We could divide K, N, and Y by any number and the production function would still apply, with constant returns. We choose to divide by N. This has the effect of stating output as output per worker, Y/N, and capital as capital per worker, K/N:

$$Y/N = F(K/N, 1, A). \tag{3.6}$$

Example: Suppose $Y = F(K, N, A) = K^{1/3}N^{2/3}A$. Divide by N to get

$$Y = \left(\frac{K}{N}\right)^{1/3} \cdot \left(\frac{N}{N}\right)^{2/3} \cdot A = \left(\frac{K}{N}\right)^{1/3} \cdot 1 \cdot A = F(K/N,1,A);$$

in other words, we replace K with (K/N) and we replace N with 1 in the production function. Output per worker depends just on capital per worker, since we are assuming that technology, A, is constant over time.

Actual investment can be either greater or less than balanced growth investment. Solow developed a famous diagram to explain what happens in the two cases. The diagram is shown in Figure 3.6.

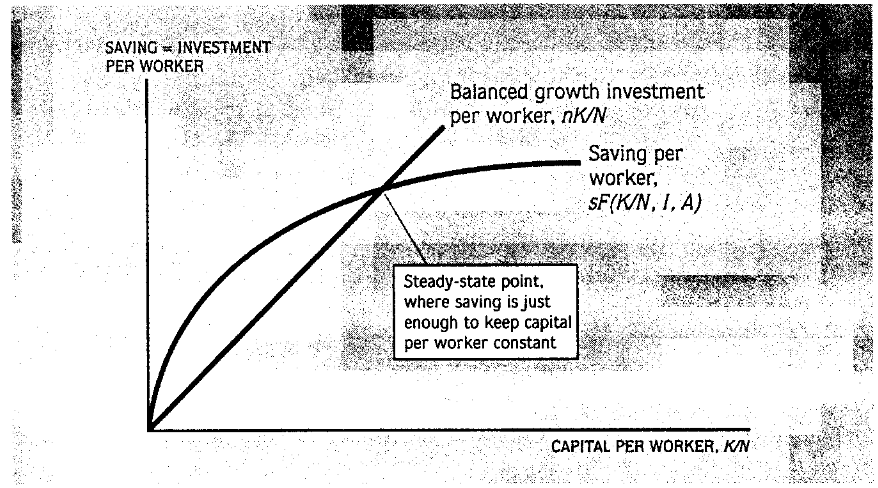


FIGURE 3.6 Solow's Growth Analysis

Solow's growth diagram shows the amount the economy saves per worker (the curving line), and the amount of investment per worker needed to keep the capital stock growing at the same rate as the labor force (the straight line). The steady state occurs at the intersection where saving generates just the right amount of investment to stay on the balanced growth path. If capital per worker is less than the steady-state level, investment exceeds the amount needed for balanced growth, and the amount of capital per worker rises. Hence the economy tends toward its steady state.

The straight line in Figure 3.6 expresses our conclusion about the amount of net investment needed to keep capital growing at the same rate as labor grows. The total amount of net investment is nK, so the amount per worker is nK/N. Because the horizontal axis is capital per worker, K/N, the amount of net investment—n times (K/N)—is a straight line with slope n. The curving line expresses our conclusion about saving per worker. Total saving is $sF(K,N,A)$, so saving per worker is $sF(K,N,A)/N$, which we can also write as $sF(K/N,1,A)$; the line is curved because it is a constant (s) times the curved production function.

The intersection of the investment line and the saving curve in Figure 3.6 is the *steady-state point.* At this point, the actual amount of investment, determined by saving, is just the amount needed to keep the capital stock growing at the same rate as labor input is growing. If the economy starts at the steady state, it will stay there.

What happens if the economy starts with less capital per worker? This would correspond to a point to the left of the steady-state point in Figure 3.6. Saving per worker, and thus actual investment, *exceeds* the amount needed to keep capital per worker constant. Each year, capital per worker increases. The economy will gradually approach the steady-state point. Similarly, if the economy starts with more capital per worker than the steady-state amount, capital per worker will decline each year and the economy will approach the steady state.

Solow showed that the growth process is *stable*. No matter where the economy starts, it will converge over time to the same steady state, with the capital stock growing at the same rate as the labor force.

The Effect of Saving on Growth

Another important conclusion from Solow's work is that, in the longer run, the growth rate does not depend on the saving rate. In the steady state, the capital stock and output both grow at the same rate as the labor force. The only factor that matters for the rate of growth of the economy is the growth of labor input. Economies that save more do not grow faster in the longer run.

What then is the impact of increasing the saving rate in the Solow analysis?

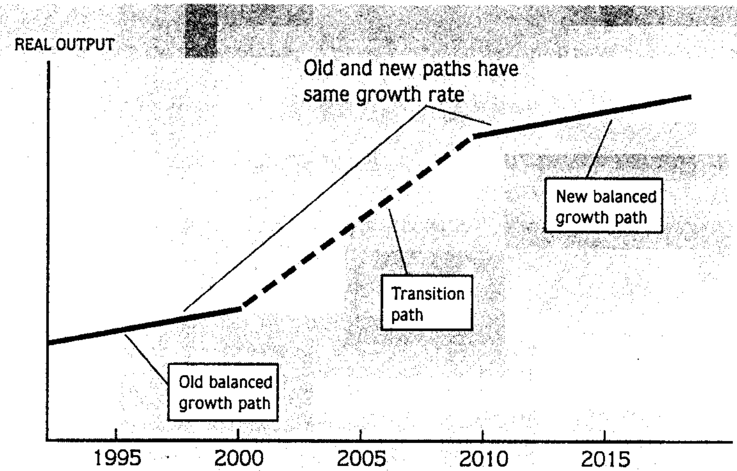


FIGURE 3.7 Transition between Balanced Growth Paths

A higher saving rate starting in the year 2000 leads to a higher level of real output. During a transition period growth is higher. The growth rates in the old and new balanced growth paths are the same.

Suppose that the saving rate suddenly rises from .02 to .04 and stays there. Then the balanced growth condition is violated with $K/Y = 2 < s/n = 4$. According to Solow's stability argument, capital will increase more rapidly than labor, and because of diminishing returns to capital, the capital-output ratio increases. The ratio will continue to increase until it reaches 4 and the economy returns to the balanced growth rate of 1 percent. There is a **transition period,** however, during which the growth rate of the economy is greater than the balanced growth rate. This is illustrated in Figure 3.7, which shows how the level of output rises as a result of the increase in saving, but the growth rate of the economy returns to the balanced growth rate after the transition period. Hence, greater saving benefits the economy by raising future GDP, but not by increasing the long-term growth rate, according to the Solow model.

BALANCED GROWTH AND THE SOLOW ANALYSIS

1. Balanced growth occurs when the labor force, capital stock, and real output all grow at the same rate.
2. Along a balanced growth path, the ratio of capital to output equals the ratio of the saving rate to the labor force growth rate.
3. Solow showed that the balanced growth path is stable: if the economy is off a balanced growth path, it will naturally tend to return to that path.
4. A higher saving rate will raise GDP in Solow's analysis of the long-run growth model, but it will not permanently raise the growth rate.

3.4 THE GROWTH ACCOUNTING FORMULA

Solow also developed a framework that can be used to determine the size of the contributions of labor, capital, and technical change to economic growth.[3] His formula is used by economists throughout the world to assign credit for growth. In its simplest form Solow's formula says the rate of growth

[3]Robert M. Solow, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, Vol. 39 (August 1957), pp. 312–320.

NEW RESEARCH IN PRACTICE
Convergence or Dispersion of Per Capita Income Around the World?

ıclassical growth model has important em-
nplications for the growth performance of
ıt countries and for economic policy. These
al implications have been the focus of ex-
research in the 1990s—collectively called
w empirical growth literature"—with schol-
ı as Robert Barro, currently of Harvard
ity, Steven Durlauf of the University of Wis-
Charles Jones of Stanford University, and
(oung of Boston University among the key
utors. This research was made possible by
ıstaking efforts of Alan Heston and Robert
ırs of the University of Pennsylvania to put
data sets from countries around the world
ımparable basis.

neoclassical growth model indicates that a
/'s long-run per capita growth rate is inde-
ıt of its saving or investment rates, but that
re long "transition periods" during which
ı can either be higher or lower than this
ın average value (see Figure 3.7). Countries
ıw *levels of physical capital per worker* are
the long-run average per capita income
hey will grow relatively fast while they
up" or *converge* to the average. Moreover,
ther below the long-run average a country
higher its growth rate will be. Thus, accord-
the neoclassical growth model, countries
ɔw levels of income per capita should grow
than countries with high levels of income
pita. Is this prediction of the model borne
' the empirical research?

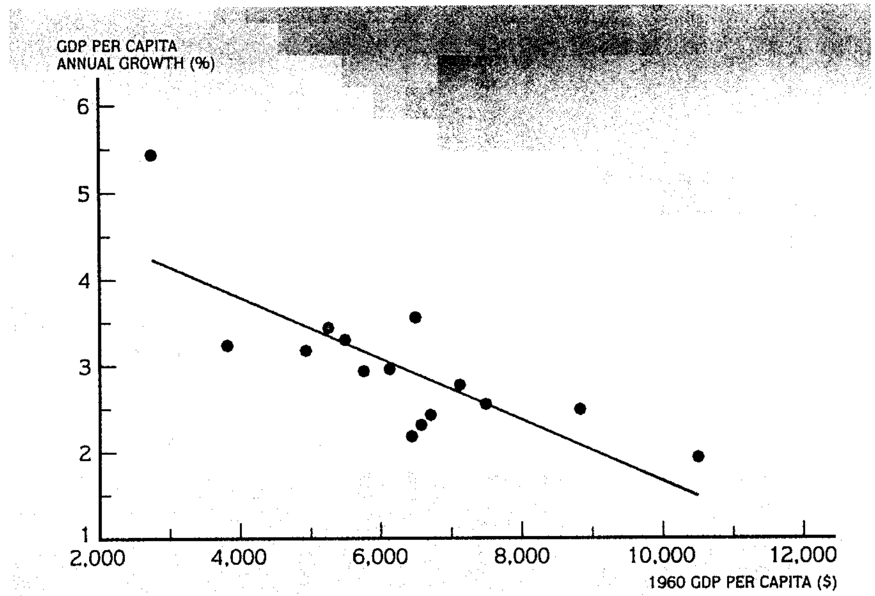
e two graphs on the next page summarize
search. The top graph pertains to the more
ced countries in the world—such as those in
ıe, Japan, and the United States. The bottom
pertains to all countries of the world, includ-
ıuntries such as China and India as well as the
ries in the top graph.

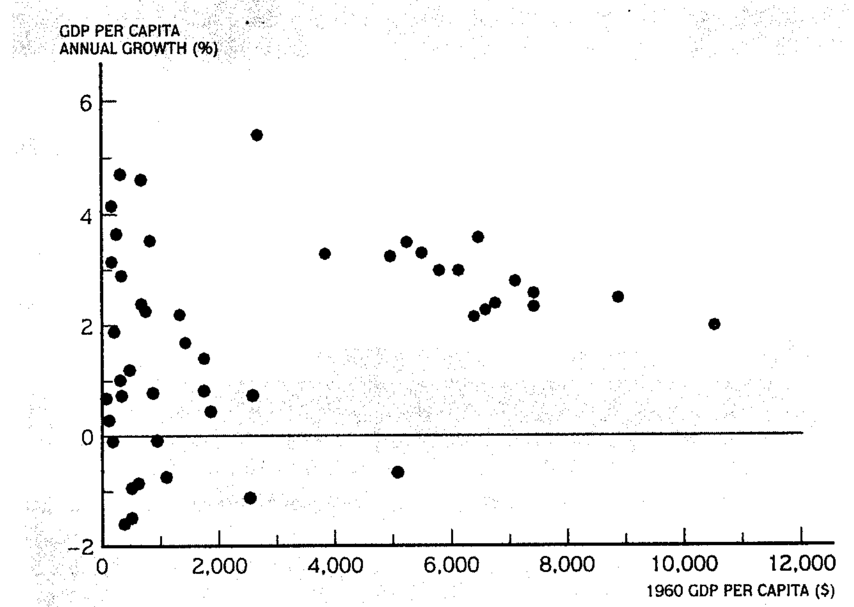
during the years since 1960. Note that there are differences in per capita income for the advanced countries as well as for the countries as a whole.

According to the model there should be a negative relationship between the level and the growth rate: that is, countries with low levels of income per capita should have higher growth rates. The top graph shows a strong negative correlation, just as the model predicts. The model appears to perform well. However, the lower graph shows virtually no correlation; there is very little "catch-up" behavior. Many countries with very low levels of per capita income have very low growth rates. The model does not perform very well when applied more broadly.

Empirical researchers have offered a good explanation for the difference between the top and bottom graphs. Countries in the top graph are similar in many of the characteristics other than physical capital that affect economic growth, such as education, public infrastructure, and stability of government policy. However, many developing countries do not have the same level of education, and their economic policy is less stable, with frequent bouts of high inflation or restrictive international trade practices. That is, the growth-related characteristics vary much more across the countries in the bottom graph than they do in the top graph. This explains the greater variation in the bottom graph and the lack of a clear negative correlation.

In other words, the explanation for the difference between the two graphs is that convergence of relatively poor countries to higher average per capita income levels is a *conditional convergence*: the countries will converge on condition that the characteristics of the countries that affect growth are similar. If a country has a poor educational system or an unstable or unreliable political system, for example, then low growth can persist even





of output equals technology growth plus the weighed rates of growth of labor and capital:

$$\frac{\Delta Y}{Y} = \frac{\Delta A}{A} + \frac{.7\Delta N}{N} + \frac{.3\Delta K}{K}. \tag{3.7}$$

The derivation of this *growth accounting formula* is shown in the appendix to this chapter. The growth accounting formula shows how total growth relates to growth in the three determinants. In words, the formula says that the rate of growth of output is equal to the rate of growth of technology plus .7 times the rate of growth in labor input plus .3 times the rate of growth of capital input. What is interesting about the formula is its lack of dependence on the details of the production function. All that matters is that technology increases the productivity of both factors in a neutral way. The weight .3 and its complement .7 are derived from data on the relative shares of capital and labor in national income. In Chapter 2 we saw that these income shares are roughly .3 and .7.

Historical Growth Accounting

The growth accounting formula can be used to determine the contributions of each factor to long-term growth in the United States during the last 30 years. In order to smooth out short-run business cycles, it helps to look at averages over longer periods, such as 10-year intervals.

The data for the United States over three 10-year periods are shown in Figure 3.8. Observe that economic growth slowed down in the mid-1970s from about 4 percent per year to about 2¼ percent per year.

According to the growth accounting formula, as shown in Figure 3.8, the most important reason for the slowdown in economic growth has been a decline in the rate of technological change. Declining growth of capital was the second most significant factor.

Exogenous Technological Change

In our discussion of balanced growth in the previous section we made the simplifying assumption that there was no technology growth; that is, the term A was a constant so that $\Delta A/A = 0$. With this assumption, along a balanced growth path with labor and capital growing by 1 percent per year ($\Delta N/N = \Delta K/K = 1$), the growth accounting formula would tell us that output growth is also 1 percent per year. That is,

$$\frac{\Delta Y}{Y} = 0 + .7(1) + .3(1) = 1.$$

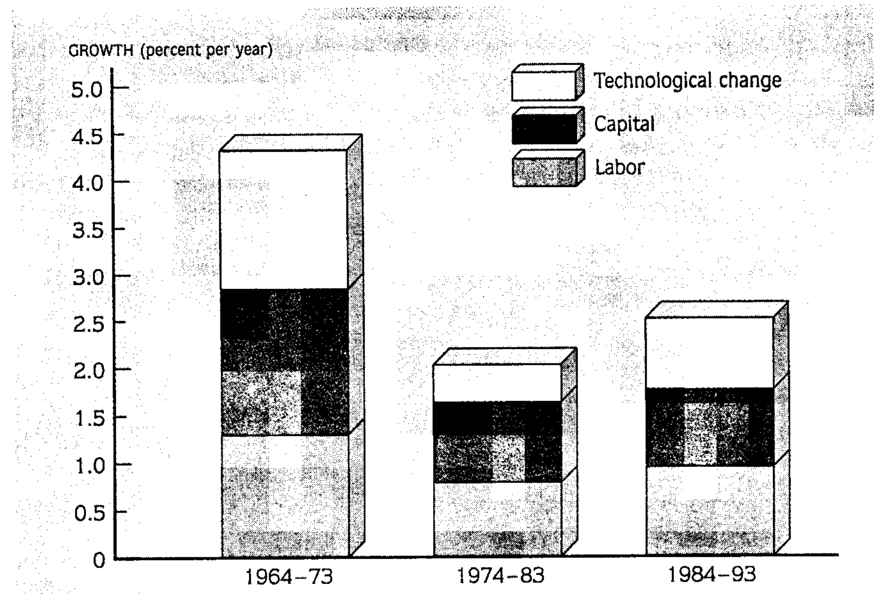


FIGURE 3.8 Sources of Growth

The height of each bar shows the annual growth rate of real GDP over 10-year intervals. Each bar is broken into blocks showing the contributions from labor growth, from capital growth, and from technological change. The contributions are calculated using Equation 3.7 in the text.
Source: Data on real output growth are from the *Economic Report of the President*, 1995, Table B-47; the labor growth data are from Table B-44; and the capital stock data are calculated from investment data in Tables B-2 and B-116.

But the growth accounting formula also shows that technology growth need not be zero. For example, suppose that technology growth is 1 percent per year ($\Delta A/A = 1$); that is, the quantity of output that can be produced with a given level of labor and capital increases by 1 percent per year. If we maintain the assumption that capital and labor both grow by 1 percent per year, then according to the growth accounting formula (Equation 3.7) output grows by 2 percent per year:

$$\frac{\Delta Y}{Y} = 1 + .7(1) + .3(1) = 2.$$

Although the capital-labor ratio (K/N) is constant, labor productivity (Y/N) increases because of the improvements in technology.

Allowing for the possibility that technology increases at a constant positive rate is an improvement over assuming that technology does not grow at all. However, we have still not explained *why* technology might increase or what factors might determine technological change. In other words, technological change—the increase in output produced with given labor and capital input—is still **exogenous** in our discussion of the neoclassical growth model. We simply assumed that technology growth was 1 percent per year. In the next section we develop an **endogenous** growth theory in which the increase in technology is not exogenous but is explained by endogenous forces within the model.

ENDOGENOUS GROWTH THEORY

Economists typically think of the long-run growth rate of output as being *exogenous* in the neoclassical growth model. As we have shown, if there is no technological change, then the growth rate of output depends only on the growth rate of labor. And the growth rate of labor ultimately depends on the growth rate of the population, which is essentially exogenous. If the saving rate rises, the long-run growth rate does not increase; it remains equal to the growth rate of labor. True, adding technology growth to the neoclassical growth model does allow the growth rate of output to change, but if technology growth is itself treated as exogenous, as in the last section, then the growth rate of output is still exogenous to the model.

An area of macroeconomic research that has been important since the 1980s is called **endogenous growth theory.** Paul Romer of Stanford University has been one of the major contributors to this theory. Compared with the neoclassical growth model, endogenous growth theory focuses on *explaining* technological growth rather than treating technology as exogenous. In other words, *endogenous growth theory endeavors to provide an explicit theory that determines the behavior of the technology factor* (A), much as we provided a theory to determine the amount of labor (N) in Section 3.2 above.

A Production Function for Technology

Recall that an increase in technology (A) is anything that increases the quantity of output produced with the same amount of labor and capital. Thus, many things can bring about an improved technology: the assembly-line method of production discussed earlier, the replacement of a horse-drawn

technological improvements, it is difficult to develop a single simple model that includes all of these activities.

One successful approach, suggested by Paul Romer,[4] is to imagine that the ideas or inventions that represent technology are produced with labor and capital much like any other good. To see how this works, imagine that there are "invention factories" throughout the economy in which new inventions are produced by workers. In fact, research laboratories are not uncommon in the United States and many countries; the job description of the researchers who work at these research laboratories is to produce new ideas and inventions. The managers of these laboratories measure production partly by the number of new **patents** that the lab produces. But the notion of an "invention factory" is more general and includes less formal though still purposeful methods of improving technology, whether in a laboratory or not.

Analogous to the production function for output (Equation 3.1), we can describe a **production function for technology** as

$$\Delta A = T(N_A, K_A, A), \tag{3.8}$$

which says that the increase in technology ΔA each year depends on the amount of labor producing the technology (N_A), the amount of capital employed in producing the technology (K_A), and the existing technology (A). The function T is the production function for technology. Note that the amount of labor and capital employed in technology production (research) is only part of the total available supply of labor and capital; that is, $N_A < N$ and $K_A < K$.

Equation 3.8 readily shows how technology is endogenous. If more labor resources (i.e., researchers) are devoted to technology production, then technology increases by a larger amount. If more capital (i.e., research laboratories and equipment) is devoted to technology production, then technology production also increases by a larger amount. In the next section we consider economic policies which might bring about such changes in labor and capital resource use.

Note that technology itself (A) also contributes to the production of new technology (ΔA). There are important spillover effects of technology. An idea developed in one laboratory can be used to help create new ideas in other laboratories. While some inventions can be patented and therefore excluded from use without permission in the production of goods, often the idea underlying the patent can be used by researchers at other laboratories. Technology as it is used in the production of new technology is an example of a good which is *nonexcludable*: one firm cannot exclude another firm from using it. Technology is inherently different from other economic goods because one can use the same idea over and over again.

Increasing the Long-Run Growth Rate

It is clear from Equation 3.8 that the production of new technology can be increased by investing more resources in research. But can the growth rate of technology—and therefore the growth rate of output—be permanently increased? Or can the growth rate be increased only during a transition period, as in the neoclassical growth model?

In an interesting and important special case of the technology production function, the growth rate can be permanently increased. To see this, suppose the technology production function is

$$\Delta A = cN_A A, \tag{3.9}$$

where c is a coefficient. This implies that

$$\frac{\Delta A}{A} = cN_A. \tag{3.10}$$

Equation 3.10 says that the long-run growth rate of technology depends on the number of workers in technology production; that is, the number of workers doing research. Hence, an increase in the share of workers doing research will increase the growth rate of technology $\Delta A/A$. Since $\Delta A/A$ appears in the growth accounting equation, this will increase the growth rate of output as well. In other words, for a technology production function like Equation 3.9 an increase in investment in research will cause a permanent increase in the rate of growth, as illustrated in Figure 3.9, and not only during a transition period as in Figure 3.7.

The reason for this crucial difference between Figure 3.7 and 3.9 is that technology—the stock of ideas—does not have diminishing returns in Equation 3.9. Observe that higher levels of technology increase researchers' productivity in producing more technology in Equation 3.9, much as higher levels of capital increase workers' productivity in producing more output in Equation 3.1. But each additional unit of capital increases output by a *smaller* amount, while each additional unit of technology increases the production of new technology by the *same* amount. If diminishing returns to technology did exist, for example, if rather than Equation 3.9 we had

$$A = cN_A\sqrt{A}, \tag{3.11}$$

then there would be no permanent effect on long-term growth. Figure 3.10

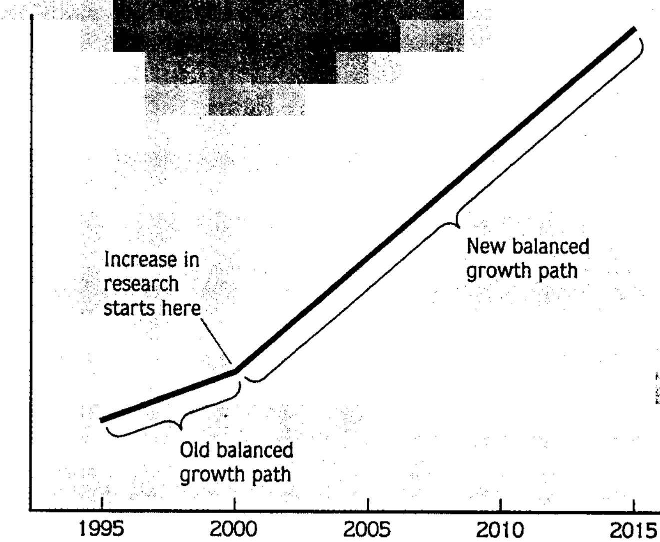


FIGURE 3.9 An Increase in the Growth Rate

If technology does not have diminishing returns in the production of more technology, then an increase in the number of workers doing research will increase the growth rate permanently, as shown here, in contrast to Figure 3.7, which shows only a temporary increase in growth.

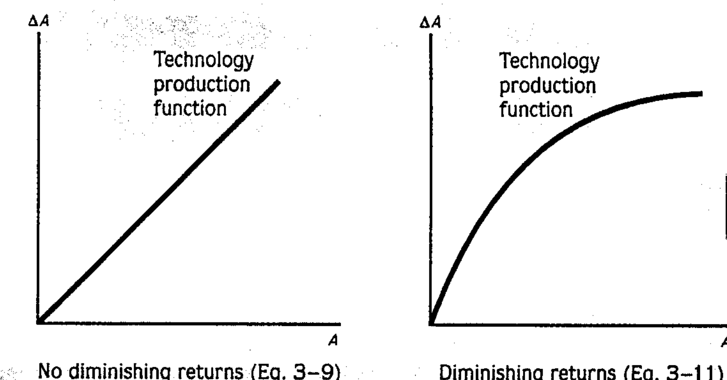


FIGURE 3.10 Two Technology Production Functions

In both cases higher technology leads to the creation of more technology. In one case there are diminishing returns, in which case growth will not increase permanently, when more labor is devoted to research.

illustrates the difference between the technology production function in Equation 3.9 without diminishing returns and the technology production function in Equation 3.11 with diminishing returns.

ENDOGENOUS GROWTH THEORY

1. Endogenous growth theory endeavors to provide an explicit theory of technology. A production function for technology is one simple way to describe how technology depends on labor, capital, and technology inputs.
2. If technology does not have diminishing returns in producing more technology, then devoting more resources to improving technology will increase the growth rate of output in the long run.
3. According to endogenous growth theory, economic policy may increase the growth rate permanently; within the neoclassical growth model, a permanent increase in the growth rate may occur only during a transition period.

POLICIES TO STIMULATE GROWTH

The government can influence all three of the determinants of growth—technological change, capital formation, and labor input. Disappointing rates of growth since the beginning of the 1970s have led to a number of federal policies to stimulate growth. Under what circumstances might a free market economy deliver an inadequate rate of growth in potential output that could be improved by government intervention? In general, government intervention is justified if a market failure exists. A *market failure* exists when there is a divergence between social and private costs or benefits of a particular activity. Many activities, such as education and research, that generate growth have social benefits that exceed private benefits. Government can encourage such activities.

NEW RESEARCH IN PRACTICE
Endogenous Growth Theory and International Trade Liberalization

There has been much interest in applying endogenous growth theory to economic policy. An important example is international trade policy—the policy of reducing barriers to international trade.

Trade policy has been much in the news in the 1990s. Two major initiatives to reduce trade barriers in the 1990s are the Uruguay Round of multilateral trade negotiations (under the General Agreement on Trade and Tariffs), which aims to reduce or eliminate tariffs in many sectors worldwide, and the North American Free Trade Area, which aims to eliminate tariffs among the United States, Mexico, and Canada.

Estimating the benefits of these trade liberalization efforts is important. While the classical theory of comparative advantage tells us that there are gains from trade, public debate can be influenced by the perceived magnitude of the gain, because in the short run certain interests can be harmed by trade liberalization.

How much effect does trade liberalization have on the economy? Estimates that ignore growth seem surprisingly small. In the traditional analysis, there is an increase in the level of real GDP, due to the more efficient allocation of resources among different economies. However, increased trade may raise the return to investment (in physical capital, human capital, and research and development). For example, access to a world market may increase the return to a new product or invention. If so, then investment will increase, and this will raise the economy's growth rate for a while. The total increase due to the trade liberalization equals the static gain in income plus the dynamic gain achieved over time as investment responds to the change in policy.

In a 1992 paper in the *Journal of Political Economy*, Richard Baldwin of Columbia University provided some quantitative estimates of these effects. He found that if trade liberalization lead a 1 percent increase in productivity (the *A* coe cient in the production function increases), the the long-run increase in output is 1.6 percent, the additional .6 percent due to capital accumu tion. Hence, approximately 6/16 = 3/8 of the long-run increase in output is due to capital ac mulations. Of course, output is not the sole variable of interest to policymakers. Increased tal accumulation requires an increase in saving Thus, although capital accumulation fostered t trade liberalization leads to a large increase in put, the effect on consumption is less.

These calculations share the characteristic the Solow model that the long-run growth ra unaffected by policy. Other models of endoge growth explicitly consider the implications of nomic policy on the long-run rate of growth. such models, trade liberalization may lead to greater R&D and human capital investment as firms and workers take advantage of the larg markets and the greater flow of ideas and kn ledge across borders. The market return to p ductivity-increasing investments is increased, this leads to an increase in the rate of growth this case, the long-run effect of trade liberali is not only a higher level of output in the futu but a higher rate of growth of output. Trade alization thus may lead to a permanent increa the rate of growth of output and consumptio this type of model is more appropriate for de ing the economy, the estimates of the benefit free trade agreement discussed above may ur estimate the true values.

The estimates of the effect of trade libera tion under the Uruguay Round used by the O of the United States Trade Representative in incorporated the increase in growth due to th crease in investment as described above.

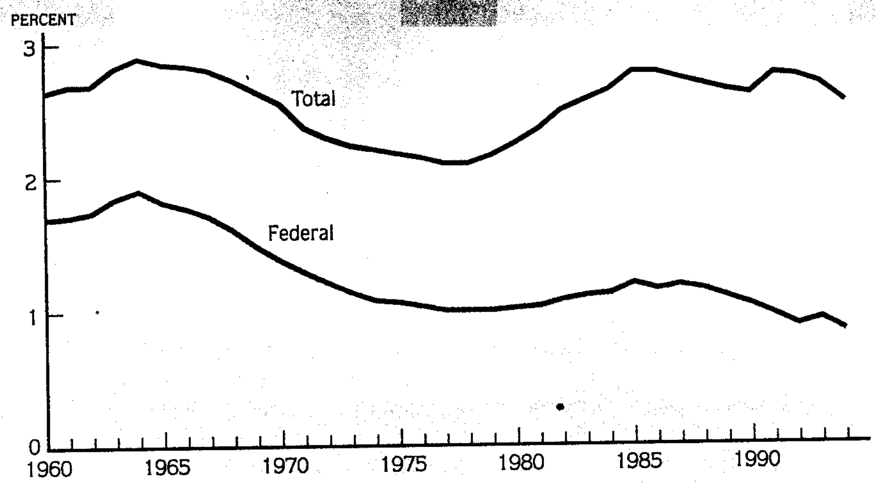


FIGURE 3.11 Federal Spending for R&D as a Fraction of GDP

Total R&D spending has been stable at around 2.5 percent of GDP. The federal portion has fallen and been replaced by rising private spending for R&D.
Source: *Economic Report of the President*, 1990.

Policies to Improve Technological Growth and Productivity

Figure 3.8 shows that technological change has fallen significantly. Hence the idea of stimulating technology has been attractive to policymakers.

Perhaps the most important role that the government can play in improving technology growth is in the area of education. In the United States, state and local governments provide most of the support for primary and secondary schools and universities. A highly skilled labor force is obviously a key ingredient to successful productivity growth.

As we emphasized with the technology production function, an important source of technology growth is investment in research and development (R&D). Figure 3.11 shows the total amount of R&D spending in the United States as a fraction of GDP. The fraction has been stable at around 2.5 percent. Figure 3.11 also shows federal spending for R&D as a fraction of GDP. The federal government's contribution to the total has declined substantially; in the 1960s the government contributed about two-thirds of the

Like education, through spillovers, discussed in the previous section, basic research may provide social benefits in excess of the private benefits that accrue to those engaged in these activities. Left to their own devices, individuals and firms will choose levels of spending on education and research that fall short of the social optimum. Government may want to encourage these activities through grants and subsidies.

The Research and Experimentation Tax Credit in the United States has provided tax incentives for research and development expenditures. This special tax credit allows firms to reduce their taxes by 20 percent of their research and development expenses. If R&D programs are an important source of technology growth, then tax incentives like these should improve growth. The use of public funds for this purpose, through the tax system, is justified if the sponsors of R&D are unable to capture the full benefits themselves.

Policies to Stimulate Capital Formation

Until recently, government policy to stimulate growth concentrated almost entirely on capital formation. A rising capital stock will add to economic growth as the growth formula in the previous section made clear. Numerically, an extra percentage point of capital growth will add about .3 percentage point to growth in output. To get an added 1 percent of growth in output, the capital stock would have to grow 3.3 percent per year.

Consider a numerical illustration. At the end of 1993, the capital stock was about $6,560 billion, counting plants, equipment, housing, and inventories. The 3.3 percent growth in capital needed to add a point to growth of output would be

3.3 percent times $6,560 billion = $217 billion in added investment.

Total fixed investment in 1994 was about $1,000 billion. Investment would have to rise by 217/1,000 = 22 percent to add just 1 percentage point to growth in output. Of course, 1 percent more growth would take us a long way to restoring the growth path that the United States experienced in the mid-1960s and would compound itself to an impressive increase in living standards in 20 years. Moreover, it is possible that the increase in new plants and machines would bring forth additional technical innovations which could spur productivity growth.

Increased growth in the capital stock requires consistently high levels of investment spending. This can occur only if there are fewer competing demands on output from households and government purchases. To expand investment, we need to reduce consumption, government purchases, or net

Under the right combination of economic conditions, a large increase in investment is possible. For example, investment was at depressed levels in 1962 when President Kennedy sponsored the first investment tax credit. The new investment incentive plus generally expansive conditions caused investment to rise from 306 billion 1987 dollars in 1962 to $401 billion in 1966, an increase of about 30 percent.

Although an increase in investment of 30 percent is feasible, it does not appear to be sustainable. Output growth can be raised by a percentage point for a few years, but then investment tends to decline to more normal levels. For example, annual growth of the capital stock reached its peak from the Kennedy stimulus at 7 percent per year in 1966, but then subsided to about 5 percent through 1974. During most of this period, the investment tax credit was in effect. Between 1975 and 1982, the growth of the capital stock fluctuated between 1 and 4 percent per year. The investment credit was in effect at a higher rate throughout these disappointing years.

GROWTH THROUGH CAPITAL FORMATION

1. Because the coefficient of capital growth in the growth formula is about .3, it takes about 3.3 percent of growth in capital to add 1 percent to output growth.
2. In 1994, it would have taken a 22 percent increase in the amount of investment to raise the growth of the capital stock by 3.3 percent.
3. Increases of this magnitude in investment have occurred in the past, but only when special incentives were combined with other favorable conditions. Even then, the high levels of investment were sustained for only a few years.

Policies to Increase Labor Supply

In the growth equation, employment growth has more than twice the leverage of capital growth. Each percentage point of extra growth of employment adds .7 percent to output growth. To put it the other way around, it takes 1.4 percent of added employment growth to increase output growth by 1 percent per year. Reductions in income tax rates are one way to stimulate work effort by improving incentives.

The income tax depresses the incentive to work by reducing the wage that workers receive for their work. On this account, one might expect that

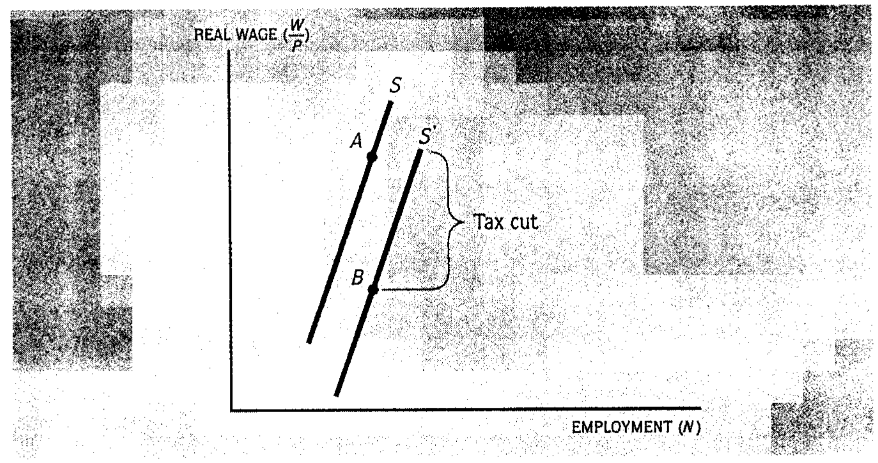


FIGURE 3.12 Shift in Labor Supply from a Tax Cut

A tax cut shifts the labor supply function downward in proportion to the cut. *S* is the labor supply schedule before the tax rate cut; *A* is an arbitrary point on it. *S′* is the supply schedule after the cut. *B* is a point on *S′* where the real wage after tax is the same as the real wage after tax on *S* at *A*. *B* is below *A* by the amount of the tax cut. The amount of labor supplied at *B* is the same as at *A* because the real wage received by workers is the same at *B* as at *A*. A downward shift in a schedule that is nearly vertical has almost no substantive effect on employment.

selling point of tax cuts put into place in 1981 and 1986 was precisely this incentive argument. But a cut in income taxes also makes people better off, which depresses labor supply. The net effect of a simple tax cut could therefore be quite small. This is illustrated in Figure 3.12. If the labor supply curve is steep, as statistical evidence seems to suggest, the intersection of supply and demand occurs at almost the same level of employment. A prediction of large stimulus to employment and output from tax cuts would be contrary to the evidence.

Growth policies need not take the exclusive form of tax cuts. In fact, the federal government's need for revenue makes it impossible to improve work incentives dramatically by cutting taxes. Another type of policy is *tax reform*. A tax reform keeps revenue the same although tax rates are cut. This can be done by reducing deductions and lowering tax rates on earned income. Because revenue is the same, the typical taxpayer pays the same amount of tax and there is no income effect. The cut in taxes due to the lower tax rate is offset by the increase in taxes due to the lower deductions. This type of reform necessarily involves a reduction in the progressivity of

:he rate applied to the last dollar of earnings. For example, a flat tax system :hat puts roughly the same tax rate on all dollars of earnings above the first 'ew thousand dollars of income could raise the same amount of revenue with lower marginal rates. This type of tax reform has no income effect to depress work. The labor supply schedule shifts by the full amount of the substitution effect.

GROWTH THROUGH INCREASED WORK EFFORT

1. Because the labor supply schedule is nearly vertical, even a large tax cut has only a small effect on employment. The substitution effect of lower tax rates raises incentives to work, but the higher level of income depresses work.
2. If the tax change is a tax *reform*, which keeps tax receipts constant, rather than a tax *cut*, it improves incentives without changing average income. Then the substitution effects are not offset by income effects.

WAGES AND THE LABOR PRODUCTIVITY SLOWDOWN

Because the real wage is equal to the marginal product of labor in the growth model, we should be able to learn about growth by looking at the movements of the real wage over time. Remember that the income side of the national income and product accounts reports the total earnings of workers. Total annual earnings divided by total annual hours of work gives a measure of the average hourly wage paid to workers in the United States. The Bureau of Labor Statistics calls this *compensation per hour.* Compensation per hour includes the value of fringe benefits as well as cash wages. Wages are the most important component of the cost of production.

Wages and prices generally moved together throughout the swings in inflation in the 1970s. Dividing the hourly average wage by the cost of living gives us the real wage. From the point of view of workers, the real wage measures the purchasing power of the wage—the amount of goods and services that can be bought with one hour of work. From the point of view of employers, it measures the real costs of labor input. The real wage does

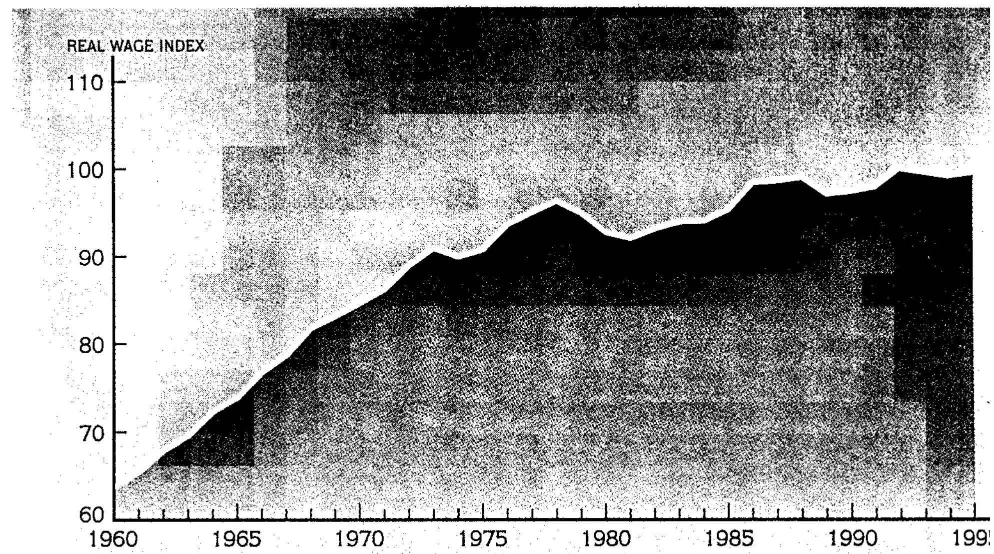


FIGURE 3.13 The Slowdown in Real Wage Growth

The real wage is the ratio of the dollar wage (compensation per hour) to the cost of living (the consumer price index). Real wage growth slowed down significantly in the early 1970s and has not yet picked up.
Source: *Economic Report of the President*, 1996, Table B-45.

not fluctuate in any systematic way during recessions or booms. Its most noticeable property is growth over time. The real wage since 1960 is shown in Figure 3.13.

After steady growth in the 1960s, the upward path of the real wage was interrupted in the early 1970s. Since then real wage growth has been much lower. One of the most pressing problems facing the U.S. economy is the slowdown in real wage growth. The behavior of real wages mirrors the behavior of productivity.

The Labor Productivity Slowdown

Productivity is the amount of output produced per unit of input. Because labor is the most important input, the most popular measure of productivity is **labor productivity,** or output per hour of labor. When economists talk about productivity, they usually mean labor productivity. A broader measure of productivity, called **total factor productivity,** is output per generalized the rate applied to the last dollar of earnings. For example, a flat tax system that puts roughly the same tax rate on all dollars of earnings above the first few thousand dollars of income could raise the same amount of revenue with lower marginal rates. This type of tax reform has no income effect to depress work. The labor supply schedule shifts by the full amount of the substitution effect.

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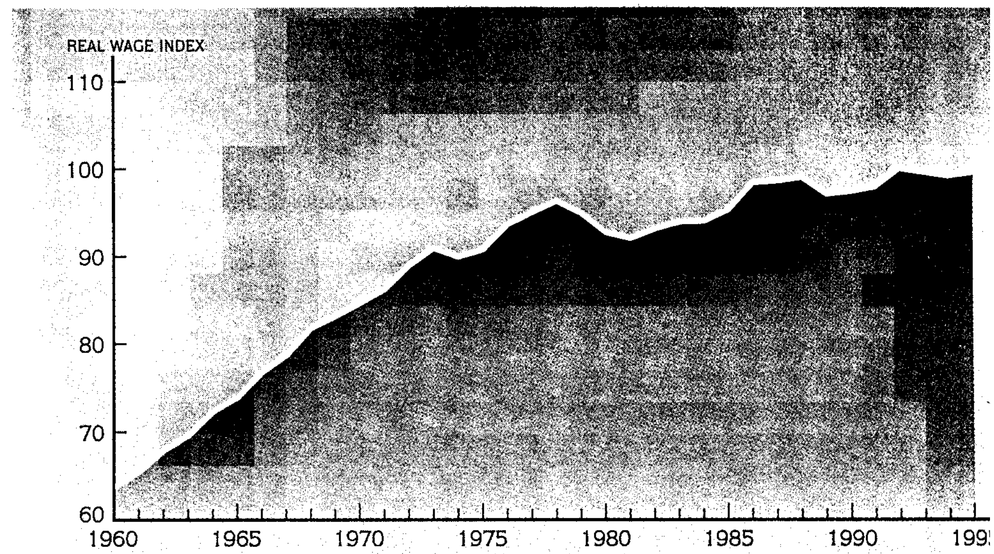

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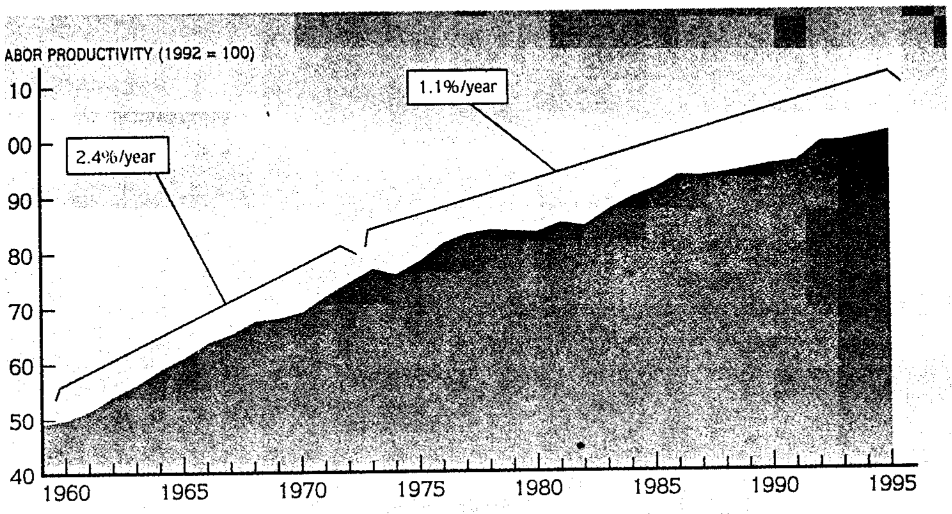

FIGURE 3.14 The Slowdown in Labor Productivity Growth

Productivity is the amount of output produced per hour of work. The general trend in productivity has been upward, but growth slowed down in the early 1970s. Productivity also fluctuates during recessions and booms.
Source: *Economic Report of the President*, 1996, Table B-45.

unit of input ("factor" is a general term for an input like labor or capital). The generalized unit counts capital, energy, and materials as inputs in addition to labor. However, output per unit of labor and total factor productivity for the United States as a whole tell about the same story in recent years.

The recent history of labor productivity is shown in Figure 3.14. Productivity has generally been increasing as workers have become more efficient and have had more and better machines to work with. This increase in productivity underlies the growth in real wages that we saw in the previous section. But productivity is also procyclical: it rises in booms and falls in recessions. Firms tend to keep skilled workers on the payroll and let them produce fewer items in slack times, rather than lay them off and run the risk that they will find jobs elsewhere. They make up for their low productivity in bad times with higher productivity in good times.

Productivity growth slowed down in the early 1970s, and this is the main reason that real wage growth has slowed down. Economists disagree about the reasons for the productivity slowdown. Some stress the role of the increases in oil prices, but the real price of crude oil is not much different from what it was in the 1950s and 1960s. Others point to a reduction in expenditures on research and development and say that technical innovation has slowed down as a result. Still others say that we are not investing enough in new machines and factories. Of all the puzzles about the recent performance of the U.S. economy, the slowdown in productivity growth is perhaps the most difficult for economists to solve.

REAL WAGES AND PRODUCTIVITY

1. The real wage measures the purchasing power of the wage payment. The real wage grew steadily in the United States until the early 1970s, when its growth slowed down.
2. Labor productivity is defined as output per unit of labor input. Labor productivity has been growing for a long time, though with fluctuations during business cycles.
3. In the United States productivity growth slowed down in the early 1970s. Growth of productivity permits the real wage to grow, and the slowdown in productivity is the main reason for the slowdown in real wage growth in the United States.

REVIEW AND PRACTICE

Major Points

1. The long-run growth model is one in which the economy is always operating at full employment. Output is determined by the labor force, the capital stock, and technology.
2. Even when the economy is operating at potential, there is some unemployment. The rate of unemployment when the labor market is in equilibrium is called the natural rate.
3. At any one time, the capital stock and technology are predetermined. Thus, output is determined in the labor market. Employment is given by the equality of labor demand and labor supply.
4. Potential GDP is the amount of output predicted by the long-run growth model. It is the amount of output the economy would produce if it were at full employment.
5. Balanced growth occurs when labor and capital grow at the same rate.

6. GDP growth can be divided into three sources: growth in labor input, growth in capital stock, and technological change.
7. In the neoclassical growth model an increase in saving does not permanently raise the growth rate.
8. In the endogenous growth model, technology growth is endogenous and the growth rate can be permanently increased.
9. The 1970s and 1980s had reduced rates of growth in output. The slowdown is attributed primarily to slower growth in technology.
10. Government policies can improve economic growth through increased expenditures on education and basic research or through tax incentives to encourage labor supply or capital accumulation.
11. Tax reform can improve incentives without reducing the tax revenue collected by government. Such a reform usually requires flattening marginal tax rates on income.

Key Terms and Concepts

long-run economic growth	production function	potential GDP
neoclassical growth model	labor demand	growth accounting formula
balanced growth capital-output ratio	labor supply	production function for technology
natural rate of unemployment	labor market equilibrium	endogenous growth theory
	full employment	

Questions for Discussion and Review

1. What are the three basic determinants of long-run growth?
2. What is the unemployment rate when the economy is in equilibrium?
3. Why is the demand for labor a negative function of the real wage?
4. Explain why microeconomic theory predicts that for labor supply the income effect is negative and the substitution effect is positive. What do empirical studies indicate about the sum of these two effects?
5. Explain why the long-run growth model predicts that the level of real GDP in any one year is determined solely in the labor market. What would happen to the real wage, the price level, and the nominal wage if the money supply were increased?
6. Why doesn't a higher saving rate increase growth in the neoclassical growth model?
7. Does an increase in the rate of growth of labor add more or less to the growth rate of output than the same size increase in the rate of growth of capital? Explain why.
8. Describe three different policies that could be used to increase the growth rate of potential GDP. Identify whether the policy is aimed at technology, capital formation, or labor supply.

Problems

NUMERICAL

1. a. The labor supply function is given by $N = 1{,}000 + 12\,(W/P)$ and labor demand is $N = 2{,}000 - 8\,(W/P)$. Draw a diagram showing these schedules. Find the equipment level of employment and the real wage.
   b. Given existing technology and the capital stock, output is given by the function $Y = 100\sqrt{N}$. Graph the production function. Does the production function exhibit diminishing marginal product of labor?
   c. Using the labor market from Part a and the production function from Part b, determine the equilibrium level of output for this economy.
2. Assume that over a 10-year period the growth rate of capital is 4 percent, the growth rate of employment is 2 percent, and the growth rate of real output is 5 percent. Calculate the growth rate of technology. Suppose that a permanent cut in the budget deficit increases investment, and the growth rate of capital rises by 1 percent. How much does the growth rate of output increase? Suppose that a tax reduction increases the supply of labor by 1 percent in one year. What happens to the growth rate of real output?
3. Suppose that the production function takes the special form $Y = AN^{.7}K^{.3}$. By taking logarithms and first differences of this production function, show that the growth formula is satisfied. (If you have had calculus, calculate the marginal products of labor and capital. Derive the labor demand function. Calculate the labor share and the capital share.)
4. Assume that the technology production function takes the form $\Delta A = 1 + N_A\sqrt{A}$. Trace out the effects of an increase in researchers' N_A on technology growth over time.

ANALYTICAL

1. Explain the relationship between the following terms: equilibrium employment, the natural rate of unemployment, and potential GDP.
2. Suppose you think technological change always improves from year to year. Using the neoclassical growth model, describe two ways in which it may be possible for equilibrium employment to decline in spite of positive growth in productivity.
3. Suppose the target rate of long-run equilibrium per capita GDP growth is 1 percent per year. Labor input and population are expected to grow at 1 percent.
   a. What rate of GDP growth is required to achieve the target for per capita GDP growth?
   b. Using the growth accounting formula, what is the required growth in the capital stock necessary to achieve the target assuming technology growth of .5 percent? What is the required growth in the capital stock if there is no growth in technology?
4. Suppose ... that ... labor supply permanently raises the rate of growth